Coastal Engineering Technical Note

GUIDELINES FOR SURVEYING BEACH NOURISHMENT PROJECTS

PURPOSE: This Technical Note presents guidance for surveying beach nourishment projects. The information has applicability to any measurement or monitoring program involving open-coast hydrographic beach profile surveys.

INTRODUCTION: Beach nourishment projects are surveyed to document the cross section of the fill material and its volume. Surveys of the beach profile furnish fundamental information needed to assess the level of protection provided by a nourishment project and to formulate local and regional sediment budgets.

Beach profile surveying techniques include special considerations that are not part of traditional land surveying procedures or of hydrographic surveys of civil works navigation projects. The purpose of this Technical Note is to summarize procedures that produce reliable and accurate beach profile surveys of beach nourishment projects. Knowledge of coastal processes and standard land surveying techniques is assumed. The Engineer Manual "Hydrographic Surveying" (U.S. Army Corps of Engineers (USACE) 1991) describes practical and operational details of standard hydrographic surveys.

Specifications for a particular beach profile survey vary according to site conditions and survey purpose. In general, however, a beach profile survey extends seaward from an established control point on land along a predetermined heading, typically along a line normal to the local trend in shoreline, to a water depth that is greater than the depth of closure at the project site. In this manner, the nearshore survey is concentrated where coastal sediment is expected to be transported by waves, nearshore currents, and changes in water level.

METHODS FOR BEACH PROFILING: A beach profile survey produces a set of distance-elevation data-point pairs on specified shore-normal lines established along the shore, usually at a fixed interval. Distance is measured from a control point located on a baseline, and elevation is measured with reference to a known vertical datum, typically to the National Geodetic Vertical Datum (see USACE 1991, Chapter 7).

Most beach profile surveys must include an *inshore survey* or "wading survey" which may be performed by using traditional land surveying techniques. A survey team member traverses the survey line holding a rod, stopping at appropriate intervals to allow an instrument operator to read and record the elevation. The type of instrument used by the operator is as simple as a level or as complex as an advanced electronic survey instrument. The wading survey continues seaward into the water until the rod holder can no longer stand steady with the survey rod. This land section of the profile is normally performed at low tide so that the cross section extends as far seaward as possible (USACE 1991).

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **NOV 1993**	2. REPORT TYPE	3. DATES COVERED **00-00-1993 to 00-00-1993**

4. TITLE AND SUBTITLE **Guidelines For Surveying Beach Nourishment Projects**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army Engineer Waterways Experiment Station,Coastal Engineering Research Center,Vicksburg,MS,39180-**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**12**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Another method is used to complete the beach profile survey in water deeper than wading depth, the *offshore survey*. The offshore survey is conducted by using a survey sled (the method recommended in this Note) or by boat-mounted echo sounder. An echo sounder survey system consists of a vessel-mounted depth sounder and positioning system. A survey sled system consists of a survey rod, or mast, supported on a sled that rides along the sea bottom while being towed. The mast supports surveying reflectors or gradations that allow the elevation of the sea bottom or beach to be read by a land-based surveying instrument. Survey sleds were used by the U.S. Army Engineer District, Wilmington, in the mid-1960s. Figure 1 shows a survey sled operated by the U.S. Army Engineer District, New York.

The Coastal Research Amphibious Buggy (CRAB) is a specially designed survey vehicle that has been used at the U.S. Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, Field Research Facility, and is considered to be a standard by which other coastal surveying methods are evaluated. The survey sled system and the CRAB are essentially identical except that the CRAB is self-propelled.

ACCURACY REQUIRED FOR MONITORING BEACH NOURISHMENT PROJECTS: The primary factor in choosing a beach surveying technique for beach nourishment projects is the required accuracy of the data collected. Beach nourishment projects involve placement of sand volumes that range from hundreds of cubic yards per foot of beach during initial construction to 20-30 cu yd/ft for periodic renourishment. Even renourishment projects with a low volume per unit distance alongshore can cost millions of dollars to construct because the placed material typically extends thousands of feet along the shore. Therefore, to account for volume change, it is imperative to minimize errors associated with beach nourishment surveys. A mean error of less than 5 cu yd/ft of beach is required to estimate sand volume with an accuracy comparable to the 10 to 20 percent cost contingencies associated with design projects.

Clausner, Birkemeier, and Clark (1986) performed a series of controlled tests of nearshore hydrographic survey methods, surveying the same beach profile five times by each method. The average difference from the mean was 0.04, 0.06, and 0.3 ft for the sled, CRAB, and digital echo sounder methods, respectively. The average vertical width of the envelope of measurements was 0.10, 0.18, and 1.02 ft for the sled, CRAB, and digital echo sounder methods, respectively.

The sled and CRAB methods have essentially the same accuracy (as they should, because the only difference between the two methods is the means of propulsion of the survey rod). The echo sounder method exhibits a much higher level of variability. For a beach profile length of 2,000 ft, Clausner, Birkemeier and Clark (1986) estimate that the sled and CRAB measurements would result in a volumetric error of about 4,400 cu yd per 1,000 ft of beach, whereas the echo sounder method resulted in an error of about 55,000 cu yd per 1,000 ft of beach. The error associated with volumes estimated by the echo sounder method is, therefore, on the order of 100 percent of the total volume of sand placed in periodic renourishment projects and 25 percent of the total

volume of sand placed in larger projects. The important conclusion is that inaccuracy renders the echo sounder method inappropriate for beach nourishment project monitoring and most beach profile surveys.

SOURCES OF UNCERTAINTY IN BEACH PROFILE SURVEY METHODS: Based upon the uncertainties associated with the various common beach survey methods, sled surveying is the most accurate and recommended approach. The wide availability of echo sounders and sounding rods often makes these methods attractive from a cost standpoint. Therefore, this Note explores sources of inaccuracies in each method so that the potential user can evaluate the significance of alternatives. Errors in beach surveying are categorized in the following sections.

Instrument error: This type of error includes inaccuracies of instruments used to acquire bottom elevation, horizontal position, and other information needed to reference elevation data to a datum, including sounding errors as discussed by Saville and Caldwell (1953). Typically, distances over which measurements are made on beach nourishment projects exceed 300 ft, which is the upper limit for which manual surveying equipment (transit or level with graded rod) are to be used (National Oceanic and Atmospheric Administration 1981). Electronic surveying instruments (distance meters and total stations) provide distance measurement accuracies, according to manufacturers, of 5 mm plus 5 ppm and angle measurements (vertical and horizontal) to 1/600 deg over the operating range of the instruments. Use of these accurate instruments for wading and sled surveys renders negligible errors that are inherent in measurement of horizontal position and elevation. The runners on survey sleds are normally 10 to 20 ft long, causing each bottom elevation reading to be an average of the elevation of the end points of the runners. Beach profile features of this scale are normally not significant if the bottom slope is correctly recorded in the data and applied in the post-processing analysis. Typical sled designs include multiple survey prism clusters on the mast that allow direct measurement of mast tilt and the corresponding elevation and position of the measurement at the base of the mast.

Methods and accuracies for surveying using an echo sounder are described by the National Ocean Survey (NOS) (1980) and USACE (1991). Echo sounders transmit a beam of acoustic energy through the water column and then measure the returning echoes which are correlated to the depth. The emitted acoustical energy is transmitted as a beam with a width that can vary from 2 to 50 deg, depending upon the purpose for which the instrument was designed. In beach profiling of depths of less than 40 ft, medium-frequency echo sounders have an accuracy of 0.25 ft, whereas high-frequency (narrow-beam) units have an higher accuracy of 0.1 ft, but with a minimum sounding depth of 5 ft and far more sensitivity to vessel motion (NOS 1980, USACE 1991). More common wide-beam boat echo sounders have accuracy limits of 0.25 to 0.5 ft. The USACE (1991) (Table 9-2 therein) estimates that echo sounders have inaccuracy of ±0.2 ft in mean depths of 5 to 20 ft, and inaccuracy ±0.5 ft in a mean depth of 35 ft.

Datum-related errors. Tide data used to reference echo sounder depth information to a datum are highly dependent upon the measurement device, its location, presence of redundant devices, and adequacy of its position within the survey area. The USACE (1991) provides guidance for acquiring tidal-correction data for echo sounder surveys. The guidance indicates that tide correction uncertainty can contribute 0.5 ft of additional error to survey data depending upon the quality of methods used to determine the water level during the survey. A typical beach nourishment project extending several miles alongshore would require significant investment in instrumentation and data reduction to provide accurate water-level information in support of echo sounder surveys, negating any apparent advantage in convenience or cost of an echo sounder survey. Tide corrections may be accurate directly offshore of a tide gage, but not for the substantial distances alongshore that a beach nourishment project typically entails. Tide gauges are often located inside bays and inlets, further reducing accuracy of a tide correction applied to the water level on the open-sea coast. Magoon and Sarlin (1970) found that the accuracy of a repetitive test hydrographic survey was 1.5 ft due to the presence of long-period (approximately 60 to 300-sec) waves at their northern California harbor site. Wave- and wind-induced set up and set down vary across-shore and may also contribute to errors in depth inferred from a tide gauge.

A major problem associated with echo sounder surveys is that data include motion of the survey vessel and squat of the vessel. The USACE (1991) states that "correcting observed depths for the superimposed effects of vessel roll, pitch, and heave is perhaps the most difficult aspect of hydrographic surveying. Since all three conditions occur simultaneously, and at different periods, either visual or automated interpretation of the analog or digital record to reduce these errors is an imprecise process, at best." In addition, it can be expected that vessel motion will be most violent close to the surf zone, the area where overlapping data are needed to compare with the wading survey portion of the profile. Motion compensators are available and are recommended for use if heave will exceed 0.3 ft, but the USACE (1991) recommends that the purpose of the survey (and the associated level of desired accuracy) should govern the decision to accept vessel motion error in the data. Echo sounder data are usually smoothed to reduce the extremes caused by vessel motion, but the error introduced by smoothing is not generally quantifiable. The time and cost of post-processing echo sounder survey data can thus be substantial.

Operator error: Measurement inaccuracy can arise through errors associated with instrument set up and data collection technique. Careful leveling and orientation of electronic surveying instruments and consistent training of instrument operators minimizes operator error in wading and sled surveys. Sources of operator error in wading and sled surveys include the degree of consistency in aiming the instrument at the center of the target, the degree to which the rod person (in a wading survey) steadies the rod, the density of data points collected along the profile, and the degree to which the rod and sled are kept on the profile heading. In a sled survey, the sled will be used to collect data continuously from the upper beach out to depth of closure with continuous control over data collection rates and sled position. Therefore, the latter three sources of operator error are negligible in a sled survey.

The primary potential source of operator error in a sled survey is the consistency achieved in aiming the instrument at the center of the target. The superior optics of modern electronic surveying instruments make this error negligible up to distances of about 2,000 ft. Beyond that distance, aiming error increases as the target size becomes smaller in the viewfinder. Optical aids on the sled mast aid in the aiming process, but experience and judgement suggest a maximum inaccuracy of about 0.05 ft and average error of about 0.02 ft at distances greater than 2,000 ft. Random error can be reduced by employing the same instrument operator for all surveys.

Surveys using an echo sounder are highly automated once the instrument is calibrated. Calibration must be conducted periodically (e.g., twice daily, see USACE 1991, Chapter 9), because of the relatively high instability of the equipment and the measurement medium (speed of sound varies with water temperature). Squat of the vessel is speed dependent and must also be considered. Mechanisms must be maintained to ensure that data are collected at an acceptable frequency. Spatial gaps can occur in the data that could result in omission of important bottom features such as bars, troughs, and shoals. Modern sophisticated hydrographic surveying systems that combine echo sounder and microwave positioning input can display via computer screen a real-time map of the survey area and position of all collected data relative to the desired heading of the beach profile (or beach profile line).

<u>Errors due to beach properties</u>: The physical characteristics of the sea floor within a survey area can introduce errors to survey data. Softness of the beach material and sea floor affect all survey methods. Inaccuracy in wading and sled surveys is introduced if the rod or sled runners penetrate the sand inconsistently. This error is minimized in wading surveys by using a hinged horizontal foot (plate) on the lower end of the survey rod to assure that the rod is placed consistently on the sand. Survey sleds will penetrate the sand surface by compressing a soft sea floor or by digging into the bottom while under tow. Both processes will produce a bias in the data rather than a random error, which will tend to cancel in a volume change calculation.

Compression of wet beach materials by a sled is negligible for commonly-used sled designs that produce a ground pressure of about 0.2 psi. Beach nourishment material generally provides a hard bottom after wetting by waves and tides unless the material is significantly nonhomogeneous, thereby further minimizing compression by a sled. Proper design of the sled runners can minimize the degree to which the sled digs into the bottom, and field tests on wet sand can quantify the amount as a function of bottom type. Sand surface penetration will introduce a bias of 0.5 cm or less into the data. Frequent and wide overlap of sled data with wading survey data within the intertidal zone provides site-specific information and an accurate mechanism for corrections to determine if the sled is digging into the sand while under tow.

Echo sounder readings are also affected by bottom softness and slope. Moderately to very hard sand bottoms in beach nourishment projects provide good signal reflectors for echo sounder measurements. However, as the bottom becomes softer and the water-sand interface becomes difficult to define, error increases. Echo sounders become more inaccurate as bottom slope increases (USACE 1991). Because the units emit a sonic cone into the water column and

the reported depth measurement depends upon the intersection of the cone with the sea floor, a sloping sea floor will introduce a bias that is a function of water depth and bottom slope. For example, if the cone width is 10 deg and a measurement is taken over a 1V:10H bottom slope in an average water depth of 20 ft, the cone will intersect the sea floor about 1.7 ft up the slope, resulting in a reported water depth of 19 ft. The error increases linearly with water depth and bottom slope. This source of error becomes large in areas where beach profiles are steep, which is often the case on newly-nourished beaches, or in areas possessing steep shoals and bars.

Monumentation errors: Inaccuracies in survey data will be introduced by lack of vertical and horizontal control in the survey area. Beach survey procedures include an accurate land survey to establish a permanent baseline and control points on each profile so that elevation and position can be accurately established. Monuments should be placed landward of the dune or the predicted extent of shoreline recession for the course of the monitoring project to avoid loss of monuments or difficulty in reoccupying survey lines. Monument elevation should be checked periodically, particularly if seismic activity or subsidence may occur.

Planning errors: All surveys, whether collected by sled or echo sounder, include overlapping of the wading survey (if one is performed) and the deeper water survey. The entire survey, or a logical subset of the survey, should be performed as quickly as possible because the survey will be considered as a reliable snapshot in time of the beach condition on the date reported for the survey. Coverage errors due to poor resolution of coastal features could result if an inadequate number of beach profile lines are used.

RECOMMENDED METHOD FOR SURVEYING BEACH NOURISHMENT PROJECTS: Because of its accuracy, simplicity of design, and wide availability of system components, the sea sled is considered to be the best method for profiling beach nourishment projects. The sea sled is normally used along beaches accessible by vehicle, with limited application to areas only accessible by boat or barge. Operations are limited to relatively hard bottoms, and sled runners can be designed to traverse areas where obstructions are present. Operation is also limited by the capability of its towing vessel (sea conditions with waves up to about 2 m in individual height). This method is appropriate for applications requiring highly accurate depth and position data. The sled system is used in conjunction with a tow-boat, 4-wheel drive vehicle, and experienced 4-person crew. The method is ideal for surveying newly-placed fill material, where projects are normally accessible by vehicle and where beach slopes preclude use of an echo sounder. Discussion in this Note proceeds under the assumption of use of a sea survey sled.

PLANNING CONSIDERATIONS. As in any field data collection effort, beach profile surveys require careful planning. The general planning considerations given below will aid in minimizing errors in subsequent analyses and designs that may employ the data. Other information can be found in CETN VI-5 (1981).

Delineation of extent of survey: Coastal beach profile surveys are used to assess the present condition of a coastal area or changes that have occurred

in the area since a previous survey or construction project. To accomplish these types of analyses, the beach survey should include an adequate length of shoreline to monitor the area of interest. In addition, adjacent areas that may influence the areas of interest or provide reference to changes made by the project may need to be monitored, for example, to provide control measurements or to account for the movement and volume of fill material transported alongshore in formulating a sediment budget.

Beach profile surveys normally extend across the entire active zone of sediment transport. In a typical coastal survey, the cross-shore limits would be the dune line and some point seaward of the estimated depth of closure. In an actively eroding area or an area that experiences frequent overwash/flooding, the profile survey would begin well landward of the primary dune or at a location not expected to erode.

Profile spacing: Each beach profile, or cross-section, is considered to be representative of the longshore segment of the shoreline on either side of the profile survey line. On an essentially straight open-coast beach, extensive analysis of the Ocean City, Maryland, beach profile data indicates that a longshore profile spacing of 1000 ft (305 m) provides adequate resolution of this beach nourishment project. In areas where the shoreline orientation changes sharply and where small-scale features need to be resolved, e.g., morphology affected by structures or local bottom features, beach profile survey lines are arranged with smaller longshore spacing (500 ft or less). Local design, permitting, and construction requirements may also dictate that survey lines be emplaced at fine spacing.

Measurement density along profile lines: Data should be acquired to adequately define sea-bottom slopes, changes in slopes, and prominent morphologic features, such as berms, bars, and shoals, along each beach profile survey line. Recommended maximum increments between survey points are 20 ft along the profile landward of the most offshore bar and 40 ft seaward of the bar.

Timing of survey: Beach profile surveys provide a snapshot or instantaneous measure of the beach condition. Therefore, the entire set of profile surveys (or a logical subset of profiles) must be performed within a time period when sediment transport during survey is a minimum. For example, adequate forecasting should be performed so that a survey is not interrupted by a storm that might change the beach condition significantly. Because some level of natural sediment transport is always occurring, beach profile surveys are performed safely and as quickly, accurately, and efficiently as possible. The time interval between separate surveys is determined according to the goals of the monitoring effort, e.g., measurements to monitor storm effects will require daily surveys whereas measurements to monitor construction will require weekly or monthly surveys.

Typically, for a beach nourishment project, a full pre-project (baseline) survey is performed, followed by a post-placement survey. Surveys are then performed twice a year, typically at the end of summer (August or September) and at the end of winter (March or April) to determine the full excursion of seasonal changes in subaerial beach width and volume. After several years,

the regular survey might be reduced to one per year, the summer survey, when low-wave conditions are prevalent. If a major storm impacts the beach fill project, a post-storm survey is made to assess the level of protection remaining in the project, to determine performance (movement of sand within the project), and to renourish (add new material) in areas where erosion occurred.

Field review of data: On-site data reduction and preliminary review of the data maximize the quality and accuracy of beach profile data and provides the most inexpensive opportunity to reacquire cross-sections that merit further investigation or to correct errors.

ACCEPTABLE SURVEY CONTROL: Beach profile surveys are always referenced vertically and horizontally to a permanent marker. Permanent markers are normally located close to shoreline areas except in cases in remote areas. These markers are established and permanently installed by agencies such as the U.S Army Corps of Engineers, U.S. Geological Survey, or highway departments. They will normally appear as a brass plate displaying the surveying agency and the date of installation.

The U.S. Department of Commerce (1974) presents the accuracies of permanent control markers. Most of the highest-order control in the United States was installed by the National Geodetic Survey, and other federal and state agencies have extended the system, particularly with third-order work. The first-order system in the United States is installed at a spacing of about 60 miles, and a second-order system exists in areas of high land value. Along most coastlines, the primary permanent control network is installed to second-order survey standards. On a typical beach nourishment project along 5 miles (8 km) of shoreline, the use of second-order control will result in a relative accuracy from one end of the project to the other of approximately 0.01 ft vertically and 1.3 ft horizontally. Permanent control markers will have an established elevation and position that can be obtained from the survey agency which installed it.

Based upon one or more local permanent control monuments, local beach monumentation is required for use in the beach survey process. Third-order land surveying techniques provide adequate accuracy for local control. Permanent survey monuments which locate either individual transects or a survey baseline should be established well landward of areas of active erosion. As recommended in CETN-VI-5, these monuments should be located landward of the mean high water line on the order of 50 times the long-term annual average annual erosion rate for the area. The monuments should also be referenced to a number of local features such as buildings or trees to facilitate recovery in the field. The elevation of the permanent monuments is referenced to the datum used for the beach profile survey, most commonly the National Geodetic Vertical Datum (NGVD), and its location is tied into the state coordinate system or latitude/longitude system.

If permanent monuments are installed for the sole purpose of establishing a baseline for the beach profile survey, temporary markers will be required on each cross-section at the time of the survey. Two markers, wooden stakes or

steel pipes driven into the beach on each profile cross-section, are used to establish the heading for the profile survey and to provide a reference for horizontal data.

SLED SURVEYING EQUIPMENT: In order to achieve accuracies as described above, a sled survey system will consist of a towable sled with mast, tow-boat or truck, and electronic distance meter/theodolite (total station) with data collector/notebook.

Electronic total stations, the most sophisticated survey instruments available, are normally used when beach profile data are collected along the full profile out to depth of closure. Less capable instruments generally will not have the range or accuracy for this application. High-quality instruments have a maximum range exceeding 2 km. Examples of such instruments are the Zeiss Elta and the Leitz Set series.

The sled and towing mechanism (truck, boat, winch, etc.) must be designed to operate in a range of conditions that allow the work to be performed in a reasonable length of time and with safety. Typical conditions for operation of a sled system will include 1-2 knots of longshore current, individual waves with heights up to 2 m for any possible wave period, and tow speeds up to 4 knots. A typical survey sled is a bottom-riding frame that supports a tall mast. Survey reflectors are affixed on top of the mast for siting and measurement by the total station. The sled is normally a pipe frame constructed of steel or aluminum with two runners. Lighter ballasted PVC sleds have been used in very calm sea conditions. The sled runners ride on the sea floor and a mast, attached to the frame and properly guyed to maintain support under tow, is visible above the water surface and waves during data collection. The mast must be designed to be stable under wave/current attack. Portable sleds typically weigh 500 to 1000 lb before ballasting.

Under calm conditions, a small inflatable boat with a small engine (50 hp) may provide adequate power and control for towing a survey sled. However, more capable vessels are commonly used with as much as 300 hp, especially in areas where occasional sea floor obstructions are present. In such cases, vessel maneuverability and power are important. Navigational control and experienced operators are critical for safe operation near the surf zone where breaking, refracting, and shoaling waves can easily capsize a boat.

DATA COLLECTION PROCESS: This section outlines the data collection process undertaken during a beach-profile survey using a sea sled. A written description of the beach profiling process using a sea sled will appear deceptively simple. It should be noted that both accuracy and *safety* of the process require experienced personnel who are trained in surveying and safety procedures for working in the nearshore. All aspects of a beach profile survey can be dangerous, with tow lines under several thousand pounds of tension, lines being handled in close proximity to boat propellers, sled hardware weighing hundreds of pounds, variable forces of waves and currents affecting all operations, and the possibility of sudden lightening storms appearing on the coast.

As the sled is pulled into shore, data are collected by the onshore survey instrument, which has been leveled and referenced to local control stakes or monuments. The instrument operator sights on the mast survey reflectors and takes a reading approximately every 40 ft of sled movement. If significant changes in bed level are noted that require more frequent data collection, the operator will stop the sled more frequently to take readings. Once the sled is towed onto the beach berm, an overlapping wading survey is performed to provide backup data in the nearshore zone and data further inland (dune areas) where the sled is difficult to use. Once a given profile is completed, the sled is moved to the next profile and the process is repeated.

Sled surveys should be well-documented in the surveyor's notebook. Meteorological and oceanographic conditions at the time of the survey, including periodic estimates of tidal elevations, time at the start of each profile, reasons for delays, etc. Photographs of beach conditions should be taken to accompany the survey data. Sediment samples may also be needed along each profile.

DATA EDITING AND ARCHIVING: Data review and editing are performed both in the field at the time of the survey and later in the office to assure that all data were properly collected and error-free. The on-site field review, facilitated by electronic data collection notebooks and portable computers, is normally performed after each profile survey or at the end of each survey day, and will verify that the survey instrument was properly set up and referenced vertically and horizontally. The review will also verify that an appropriate density of data points was collected along the profiles so that no important bottom features were missed or incorrectly represented. On-site comparison of profile shape and offshore contour positions indicates consistency with previous surveys. The field review allows the survey team to return to an area if additional surveying is required.

Data editing at the office consists of more detailed and quantitative examination of the survey data. The file is again reviewed to eliminate or correct erroneous data points and instrument set up errors. Plots of the cross sections together with previous surveys will also help to identify potential survey errors. The data are converted to and archived in ISRP format (Birkemeier 1984) and in an ASCII file containing elevation and position (state plane coordinates or equivalent) of each data point.

ADDITIONAL INFORMATION: This Note was written by Mr. William G. Grosskopf, Offshore and Coastal Technologies, Inc., East Coast, and Dr. Nicholas C. Kraus of the Coastal and Hydraulics Laboratory, US Army Corps of Engineers. Contact Dr. Julie Rosati, Julie.D.Rosati@usace.army.mil for additional information.

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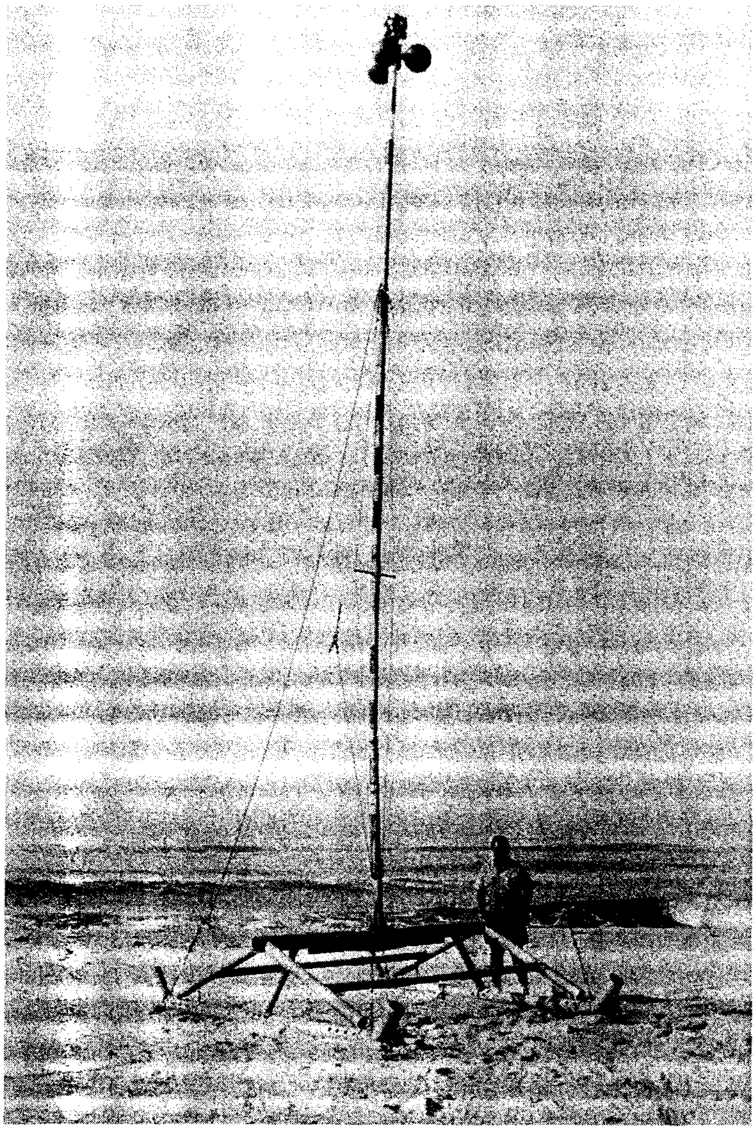

Fig. 1. Sea survey sled operated by U.S. Army Engineer District, New York